Autonomous Cars and Society

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Table of Contents

Table of Figures

Abstract

This document explains the impact of autonomous vehicles on society. The project includes a background section which gives information about the history and technology of autonomous vehicles. To evaluate the socio-economic effect of the autonomous vehicles, we review the benefits and economic savings that will emerge as a result of the introduction of autonomous cars in the economy. Impacts on safety, traffic flow, fuel economy, professional driving and culture are some of the important issues mentioned in this report.

1 Technology of Autonomous Vehicle Systems

1.1 Introduction

People drive their cars to work, to go shopping, to visit friends and to many other places. Children take the bus to school. The economy depends largely on the goods that are delivered by trucks. This mobility is usually taken for granted by most people and they hardly realize that transportation forms the basis of our civilization. As the cities grow and the population increases, more traffic is generated which has many adverse effects. Not having a proper transportation system costs people their safety, time and money. The need for a more efficient, balanced and safer transportation system is obvious. This need can be best met by the implementation of autonomous transportation systems.

In the future, automated systems will help to avoid accidents and reduce congestion. The future vehicles will be capable of determining the best route and warn each other about the conditions ahead. Many companies and institutions are working together in countless projects in order to implement the intelligent vehicles and transportation networks of the future.

1.2 Background

An autonomous vehicle is fundamentally defined as a passenger vehicle that drives by itself. An autonomous vehicle is also referred to as an autopilot, driverless car, auto-drive car, or automated guided vehicle (AGV).[1] Most prototypes that have been built so far performed automatic steering that were based on sensing the painted lines in the road or magnetic monorails embedded in the

road.[2] Today's researchers are using sensors and advanced software together with other custom-made hardware in order to assemble autonomous cars. Although the prototypes seem to be very successful, a fully autonomous car that is reliable enough to be on the streets has not been constructed yet. This is mostly because of the difficulties involved in controlling a vehicle in the unpredictable traffic conditions of urban areas. While better hardware is being developed there are important limitations on the artificial intelligence side of the research. It would be fair to say that the future of the autonomous cars mostly depends on the development of better artificial intelligence software. On the other hand most hardware that is being used on the cars seems to be doing well in terms of reliability, response time and accuracy. The control mechanism of an autonomous car consists of three main blocks as shown in **Figure 1**.

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│  │            │       │   Logic    │        │ Mechanical │        │
│  │  Sensors   │──────▶│ Processing │───────▶│  Control   │        │
│  │            │       │    Unit    │        │  Systems   │        │
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│                                                                    │
│   -laser sensors        -Software            -Consists of servo motors │
│   -cameras              -Decision making      and relays           │
│   -radars               -Checking functionality  - Driving wheel control │
│   -ultrasonic sensors   -User interface       -Brake control       │
│   -GPS, etc.                                  -Throttle control, etc. │
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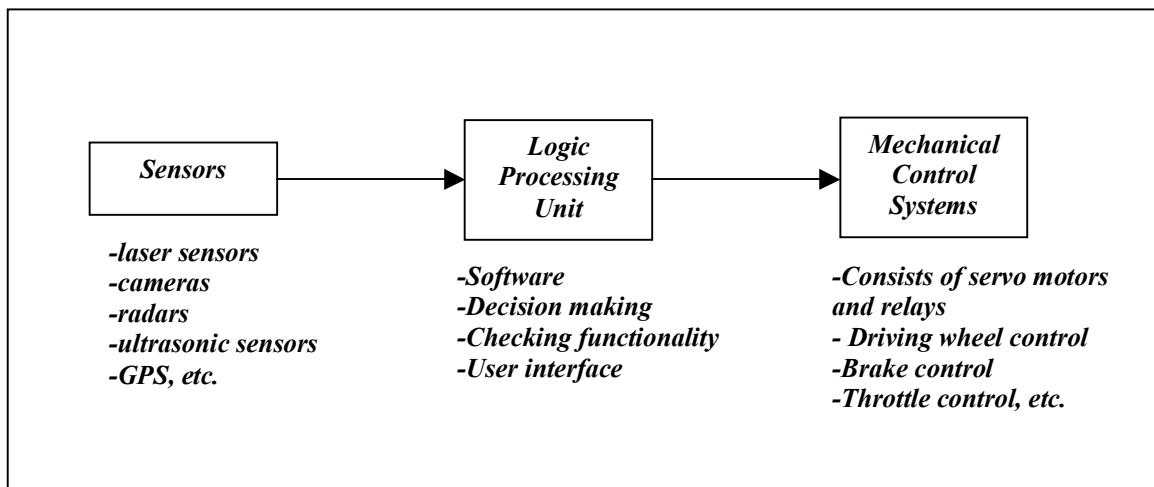
Figure 1 - Basic Block Diagram

Most autonomous vehicle projects made use of stock cars and modified them, adding "smart" hardware to create automated cars. The advantage of using stock cars is the ease of obtaining the car through sponsors. The stock cars help convey the message autonomous vehicles are not science fiction anymore and these systems can be implemented on normal cars. A good example to a project

that made use of a stock car is the **Carsense**[3] project. This project's goal was implementing a system that would enable a car to work fully-automated at lower speeds but with more complex driving tasks. These tasks include situations in dense traffic environments in and around urban areas that have traffic jams, tight curves, traffic signs, crossings and ancillary traffic participants such as motorbikes, bicycles or pedestrians.[4] This type of a system is referred as a "Low Speed Automation" (LSU) system. In fact, LSU systems which take over the full control of the vehicle in congested stop-and-go traffic can be commercially available within a few years, assuming that the related laws and regulations are altered.

The **Carsense**[3] project was sponsored by the European Commission and carried out between the years of 2000 and 2002. A consortium of 12 European car manufacturers, suppliers and research institutes worked together for this project. A variety of sensors were used in order to increase accuracy which included short and long range radars, laser telemeters, as well as vision and stereo-vision devices. ***Figure 2*** shows the sensors and their positions on the car for this project. Test Vehicle used in this project was an "Alfa 156 Sportwagon 2.0 Selespeed".[4]
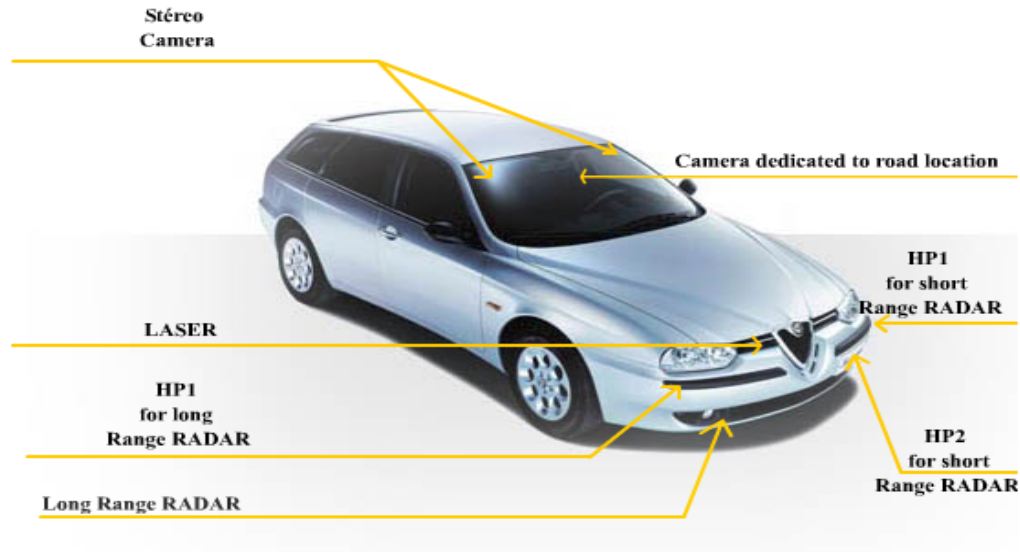
Figure 2 - Carsense Prototype[3]

There are also projects that include designing a new vehicle as well as an autonomous control system. One example of this kind of projects is the ParkShuttle[5] project in Netherlands. This project aimed to create a fully automatic shuttle system that makes use of a low-capacity automatic navigating vehicle that operates without any physical guidance. The shuttle finds its way automatically and travels on a simple ground-level asphalt track.[5] The pilot project route links the business park Rivium to the metro station Kralingse Zoom in Rotterdam. The prototype can be seen in **Figure 3**. A short descriptive system layout for the ParkShuttle[5] on demand system is also shown in **Figure 4**.

Figure 3 – ParkShuttle[5]
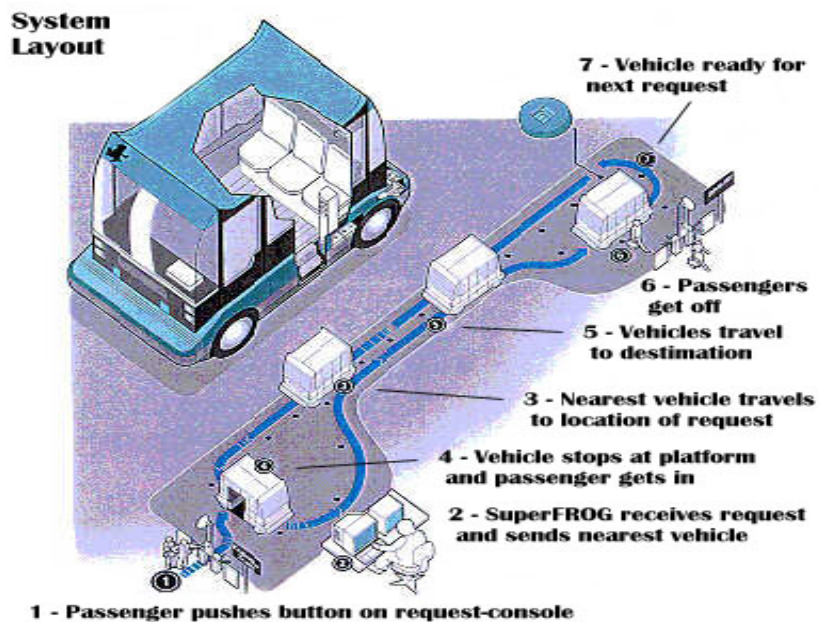
Figure 4 - ParkShuttle System Layout[5]

1.2.1 History

The first known worthy attempt to build an autonomous vehicle was in 1977. The project research was carried out by Tsukuba Mechanical Engineering Laboratory in Japan. The car functioned by following white street markers and was able to reach speeds of up to 20 mph on a dedicated test course.[6]

The breakthrough in the development autonomous vehicles came in the 1980's with the work of Ernst Dickmanns and his team at Bundeswehr Universität

München. Their prototype was able to achieve 60 miles per hour on the roads without traffic. Another important milestone in the history of autonomous vehicles was AHS's revolutionary demonstration made in 1997 that included more than 20 fully automated cars.[7] The demonstration was carried out on a California highway and completed without a glitch. This event stands as gaining the most media coverage of any Intelligent Transportation System activity in US until the 2005 DARPA Challenge. Nowadays we are looking forward to see the next DARPA Challenge that will take place in an urban environment in November 2007.

During the 1990s, the basic capability for car automation systems was demonstrated in Europe, Japan and the United States respectively by the PROMETHEUS program, AHSRA (Advanced Cruise-Assist Highway System Research Association) and AHS (Automated Highway System) program. The European projects were completely based on vehicle intelligence, while the Japanese developed systems that were highly vehicle-highway cooperative. The U.S. projects made use of both techniques in their autonomous vehicle systems.[8] The 1990's projects were very immense and unique. The ASH program of US resulted in the mighty Demo'97. The project was abandoned after this demonstration because of being too long in scope of time. Around 2000 smaller and more private attempts emerged. These smaller projects are mostly short-scoped and more safety based. Currently there are many small and mid-sized projects in progress which are no mach for programs like PROMETHEUS in size, but they show great potential for future development of autonomous transport. *Table 1* shows the chronological listing of some important events and projects in the history of automated vehicle systems.

Date	Event	Info
1977	Tsukuba Mechanical engineering lab built the first self-driving vehicle.	It achieved speeds of up to 20 miles per hour, by tracking white street markers for up to 50 meters.
1980's	Work of Ernst Dickmanns and his team at Bundeswehr Universität München	Vision-guided Mercedes-Benz robot van could achieve 60 miles per hour on streets without traffic.
1987-1995	Pan-European PROMETHEUS Project (the largest autonomous vehicle project ever)	The prototype car achieved speeds exceeding 110 miles per hour on the German Autobahn. Unlike the early robot cars it drove in traffic, executing maneuvers to pass other cars.
1995	CMU Navlab "No Hands Across America Project"	The car made almost 3000 miles 98.2% autonomously. Throttle and brakes needed human control.
1997	AHS Demo'97	More than 20 fully automated vehicles operated on a highway in San Diego, California
2000-2002	CARSENSE	This project concentrated on slow speed driving with more complicated situations such as, traffic jams. The prototype made use of a wide range of sensors including stereo camera vision, lasers and radars.
2000	AHSRA Demo 2000 (Japan)	38 cars, buses and trucks illustrated the ideal system for reducing road traffic accidents using driver information and control assist systems. The automation system made use of magnetic sensors on the road.
2000-2003	CHAMELEON	The system was composed of a sensor module for obstacle detection (vision system, medium range radar, laser scanner, laser, short range radar) and a processing module for crash prediction (control unit). Output was intended to be used by an advanced passive safety system on board.
2001	DARPA Demo III	Demonstrated the ability of unmanned ground vehicles to navigate miles of difficult off-road terrain, avoiding obstacles such as rocks and trees.
2001-2004	ARCOS (Research Action for Secure Driving) (France)	This project aimed reducing accidents by 30% The main functions were: -controlling inter-vehicle distances; -avoiding collisions with fixed or slowly moving objects; -avoiding lane departure; -alerting other vehicles of accidents.
2001-2004	CarTALK 2000	This European project focused on the new driver assistance systems which are based upon inter-vehicle communication.

2001-2005	INVENT (Intelligent traffic and user-oriented technology) (Germany)	The main purpose of this project was to improve the traffic flow and safety by using intelligent and user-friendly systems. The prototypes were tested in the city of Magdeburg, Germany in April 2005.
2004-2008	PREVENT (EU)	This project is aiming to develop and test safety-related applications, using existing devices that can be integrated into on-board systems for driver assistance. PREVENT will warn drivers in hazard situations and take action if the driver doesn't respond.
2005	DARPA (The Defense Advanced Research Projects Agency) Grand Challenge II	It was designed to be a race in the dessert environment with no traffic. The course was predefined by GPS points and obstacle types were known in advance. Stanford Univ. team won the race.
Nov. 2007	DARPA Grand Challenge III	DARPA will hold its third Grand Challenge competition on November 3, 2007. It will be held in an urban environment, featuring autonomous ground vehicles conducting military supply missions.

Table 1- History of Autonomous Vehicles [1, 3, 4, 6, 9, 10, 13]

Figure 5 shows the placement of the test hardware in one of the cars used in

AHS Demo'97.
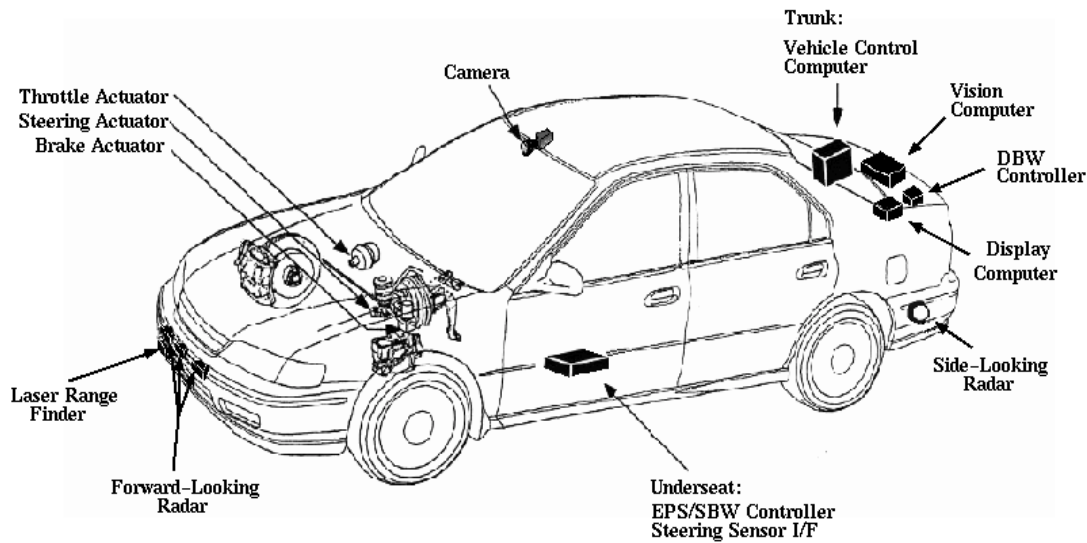
Figure 5 - Placement of Hardware, Demo'97[11]

Before 2000 most car manufacturers seemed uninterested in building a fully

autonomous car because the projects seemed to be very long scoped. All of the

big autonomous vehicle projects done in the 1980's and 1990's have been mainly

funded by the governments of technologically leading countries such as USA,

Germany and Japan. Now, the private sector is more involved in this area. Almost

every car manufacturer has an autonomous car project or sponsors external

projects. Nowadays the number of projects in this area is so high that it is hard to

keep a count. The best illustration of this is the increasing number of teams that

are participating in the DARPA Challenge.

1.2.2 Future

The transition to an automated transportation structure will greatly prevent many problems caused by the traffic. Implementation of autonomous cars will allow the vehicles to be able to use the roads more efficiently, thus saving space and time. With having automated cars, narrow lanes will no longer be a problem and most traffic problems will be avoided to a great extent by the help of this new technology. Research indicates that the traffic patterns will be more predictable and less problematic with the integration of autonomous cars.[12]

Smooth traffic flow is at the top of the wish list for countless transportation officials.[7] *"We believe vehicle-highway automation is an essential tool in addressing mobility for the citizens of California,"* says Greg Larson, head of the Office of Advanced Highway Systems with the California Department of Transportation, who notes that *"The construction of new roads, in general, is simply not feasible due to cost and land constraints".*[7]

It is clearly seen that most government officials and scientists see the future of transportation as a fully automated structure which is much more efficient than the current configuration. All developments show that one day the intelligent vehicles will be a part of our daily lives, but it is hard to predict when. The most important factor is whether the public sector will be proactive in taking advantage of this capability or not. The Public Sector will determine if the benefits will come sooner rather than later.

Car manufacturers are already using various driver assist systems in their high-end models and this trend is becoming more and more common. Since these assist systems are very similar with the systems that are used in autonomous car

prototypes, they are regarded as the transition elements on the way to the implementation fully autonomous vehicles. As a result of this trend, the early co-pilot systems are expected to gradually evolve to auto-pilots. More detailed information on the driver aid systems can be found in the following technology section.

1.3 Technology

There is a wide range of technologies being used to implement autonomous vehicles. The most available are low autonomy systems that require some driver interaction. Sensors and equipment used in these low autonomy systems are steps toward a fully autonomous package for vehicles.

1.3.1 Control Systems

This section discusses the various systems and sensors used to control autonomous actions of the vehicle. The methods used for controlling the vehicle are broken down into lateral control and longitudinal control. The lateral controls focus on the steering, while the longitudinal controls help with the speed control.

1.3.1.1 Lateral Control

A large part of the lateral control is keeping the vehicle in its chosen lane and on the road. Current technologies are Lane Departure Warning Systems (LDWS), and Lane Keeping Assist Systems (LKA). There is also a new Parallel Parking Assist currently available from some automobile manufactures.

1.3.1.1.1 Lane Departure Warning System (LDWS)

The purpose of LDWS is *"to avoid run-off-road and sideswipe crashes and to support the driver in lane-keeping."* [8]   In order to do this, the vehicle must be able to sense the lane and road boundaries, and also where the vehicle is positioned in the lane.   There are various methods being researched to perform this task, which are embedded magnetic markers in the roadway, highly accurate GPS and digital maps, and image processing.

The most accurate method for finding the lane is the embedded magnetic markers in the road. These markers would emit a magnetic field which could then be detected by sensors on the vehicle. This gives the vehicle a path to stay in, which is in between the sets of road magnets. While this system may be the best approach for the vehicle to see a path in the road, it is not the best to implement. Implementation would require embedding magnets in all of the current roads and any future roads that would be constructed. This task, while possible, is out of reach because of the amount of roadway that would need to be covered.

"Another approach is to combine highly accurate digital mapping of the roadway lanes with satellite positioning accuracies in the order of 0.5m or better." [8] This method requires detailed digital maps to be made and extremely accurate GPS to see where the vehicle is inside the lane on the map. This technique is currently being evaluated in Minneapolis, MN for transit busses. The busses are allowed to use the shoulder of the road which is only 10 feet wide. This small lane causes the drivers to be very cautious and drive slow during the commute. A lab at the University of Minnesota has implemented the digital map and GPS technology on some of the busses. The system will give the driver physical

feedback on the steering wheel, which cues the driver that they are approaching the edge and must make a correction. This allows the drivers to operate at higher travel speeds. While this and the magnetic marker methods are plausible in controlled, small environments, they are not the best choice for general driving use.

The best way for everyday driving has been determined to be the use of image processing. This detects existing lane markers to create a virtual lane in the video camera. *"Here, the predominant approach by far is the use of a monochrome video camera and image processing to extract the lane and road edge markings from the image."*[8] The down side to this method is that the road markings are not always clearly displayed. They can be covered by snow, worn down, or difficult for the camera to see because of highly reflective road conditions. This is counteracted by using special detection algorithms that can even detect tire lanes in the snow. There are still issues where the system may become confused or the ability for the camera to transition between drastically different lighting. Another way to detect lane departure is downward looking infrared sensors on the bottom of the car. These sensors look for the change in the reflectivity of bare pavement and lane markings. However, this system can only detect the lane departure as it is occurring and the camera system could predict lane departure from sensing the road ahead. All of these systems provide a range of warnings from audible beeps to physical feedback to the driver to alert them that they are departing the lane.

Typical interstate
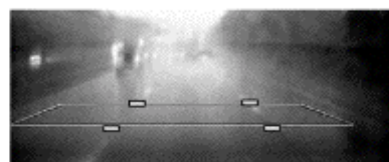
Rain
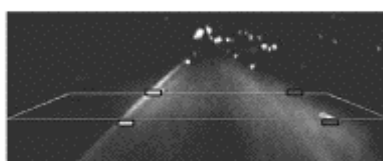
Night driving

Snow

1.3.1.1.2 Lane Keeping Assist System (LKA)

The Lane Keeping Assist System (LKA) is used as a convenience product for the driver of a vehicle. While you are driving on a highway, there are small adjustments that need to be made to the steering in order to stay in your lane. The LKA helps a driver by providing small amounts of actuation to steering to keep the driver in their lane. While driving on the highway, the amount of torque that is necessary to turn the wheel is a very small amount. Because of this, it makes it very easy for any driver to override the assistance provided by the system if necessary. There are onboard sensors that analyze different factors, such as crosswinds, road surface geometry, detection of the current lane and curves. These sensors include radar, lidar (laser radar), ultrasonic range finders, and image processing with video cameras. One problem for this system is the ability for the driver to remain alert while the car is adjusting small amounts of steering for them. In response to this problem, the developers have made is so that there is required driver input over time, otherwise the system will sound an alarm.

There are transit applications to this system as well. One company, IrisBus[14], has developed a method called CIVIS using image processing and special markings on the road. The camera tracks a double dashed line and processes the information to the LKA system to steer the bus to follow the lines. This system is currently being used in France since 2001, and also has an installation in Las Vegas which arrived in 2004.
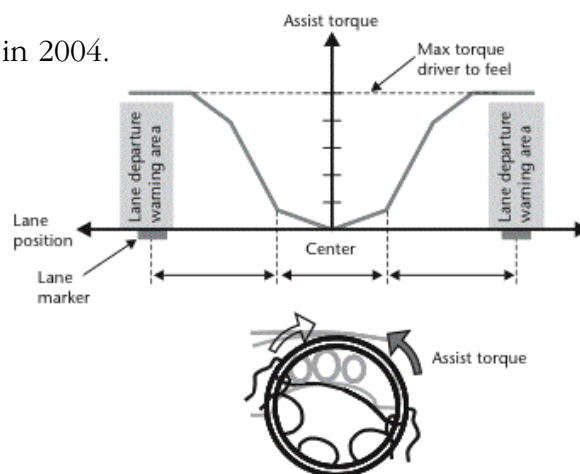
1.3.1.1.3 Parallel Parking Assist

Parallel Parking Assist systems are currently available from automobile manufacturers for public use. The first system was introduced by Toyota in 2003. This incorporates the rearview camera to help with parallel parking assist. The user pulls past the spot they wish to park in, engages reverse, and then using the dashboard screen which displays what the rearview camera can see the driver moves a box over the spot they wish to park in. After making confirmations, the driver must control the braking and acceleration, but the vehicle will do all of the steering to back into the spot successfully. The user must then engage the drive gear again to pull forward and finish the parallel park. This system provides a convenience for users in cases where parallel parking may be difficult.

1.3.1.2 Longitudinal Control

Longitudinal control encompasses the forward and reverse directions of the vehicle. It has applications to control the speed of the vehicle and assist the driver with forward and reverse driving tasks. These applications include rear sensing to assist with parking, Adaptive Cruise Control (ACC), and pre-crash break assist.

1.3.1.2.1 Rear Parking Assist

There are many systems currently available to assist the driver with parking. The most common is the use of ultrasonic range finders embedded in the rear bumper of the car that give the driver a changing audible sound as the distance decreases. The downside to these devices is that they only work in very short range, that of only a few meters. Newer devices include rear facing video cameras that display what is seen from the rear of the vehicle when the driver shifts into reverse. Along with the video processing, there is an overlay of guide lines that guide the driver into the spot and tells them when to stop. Also, the use of radar in similar systems is being developed. It is more accurate than the ultrasonic range finders and allows for greater application. One application being tested was the use of radar in the front and rear of the car to sense objects out of the driver's view. As the driver approaches the objects, the car assists in braking to avoid making contact with the object.

1.3.1.2.2 Adaptive Cruise Control (ACC)

Adaptive cruise control is used to aid the driver in driving by controlling the speed at which the vehicle moves relative to the vehicles in front of it. There are a variety of ACC systems such as high-speed ACC, low speed ACC, and full ACC. Different sensors can be used to provide an ACC system to the driver. The most commonly used sensor right now is radar based ACC. This uses radar to find the range between the vehicle in front of the driver and it also calculates the rate at which the vehicle ahead is approaching or moving away. Using this calculation, the system will adjust the speed of the vehicle to maintain a set distance from the vehicle ahead. If a different vehicle moves into the lane, the ACC will adjust the speed to return to the set distance. There are also lidar based systems which use laser technology to find the range between vehicles.

High speed ACC has the driver set a speed as in a normal cruise control system. When an object approaches, the ACC controls the braking and throttle to match the speed of the vehicle ahead. Once the path ahead is clear, the system returns to the set cruising speed. High speed ACC is the easiest to implement because the sensors are able to accurately detect what objects are other moving vehicles traveling at a similar speed.
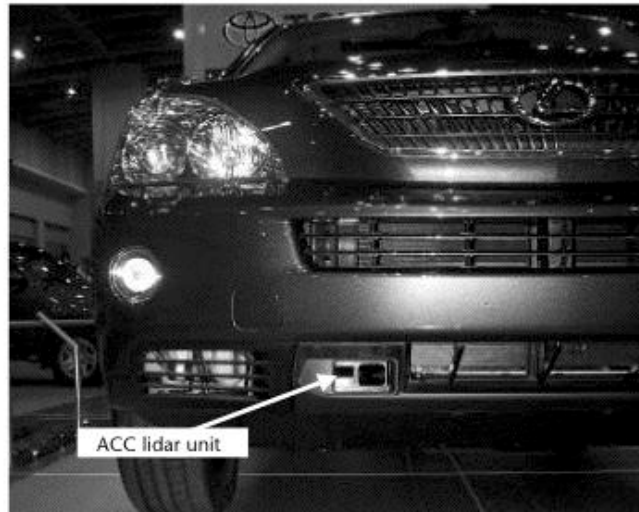
Figure 8- ACC Sensor Location [8]

High speed ACC is currently available from automobile manufacturers such as Audi, BMW, DaimlerChrysler, GM, Honda, and Toyota.

Low speed ACC is intended for use in more congested areas of traffic. However, the system will not completely stop the vehicle if it is necessary. It will warn the driver of an approaching object if it gets to its lowest speed level. The driver is then responsible to stop the vehicle, and must also make the vehicle resume driving after a stop has occurred.
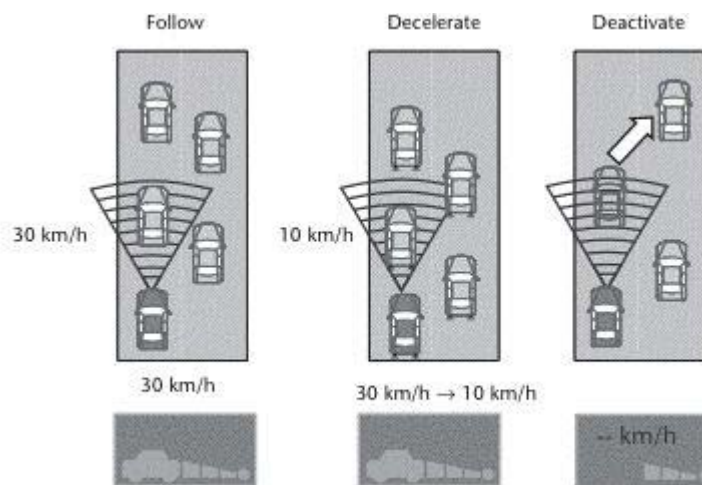
Figure 9 - Low Speed ACC [8]

Full ACC would be a combination of high and low speed ACC and step toward autonomous speed control. The system could be activated and would adjust between high speed highway driving and low speed traffic or city driving. This would allow the driver more freedom to concentrate on steering and what is going on around the vehicle. This development is necessary in obtaining a fully autonomous vehicle, and is currently under testing in the ARCOS project.

Pre crash brake assist uses ACC to detect possible collisions by calculating the speed at which a driver is closing in on an oncoming object. If the rate is high enough, the system will pre-arm the brakes so optimum braking can be achieved. This helps to reduce stopping distance and also speed of impact if it were to occur.

1.3.2 Full Autonomous Systems

In order to achieve a fully autonomous passenger vehicle, there must be seamless integration of both lateral and longitudinal control systems. They must be developed to the point that the public can trust the systems to be reliable and robust.

The earliest fully autonomous system we may see in production is a low speed version. This would be a combination of low speed ACC and lane keeping assistance. This would be efficient for use in highly congested traffic. An Intelligent Highway System (IHS) is currently under development in China. This would provide the vehicle with information about the road ahead such as safety alerts or traffic details. The IHS would also assist in automated operation of vehicles.
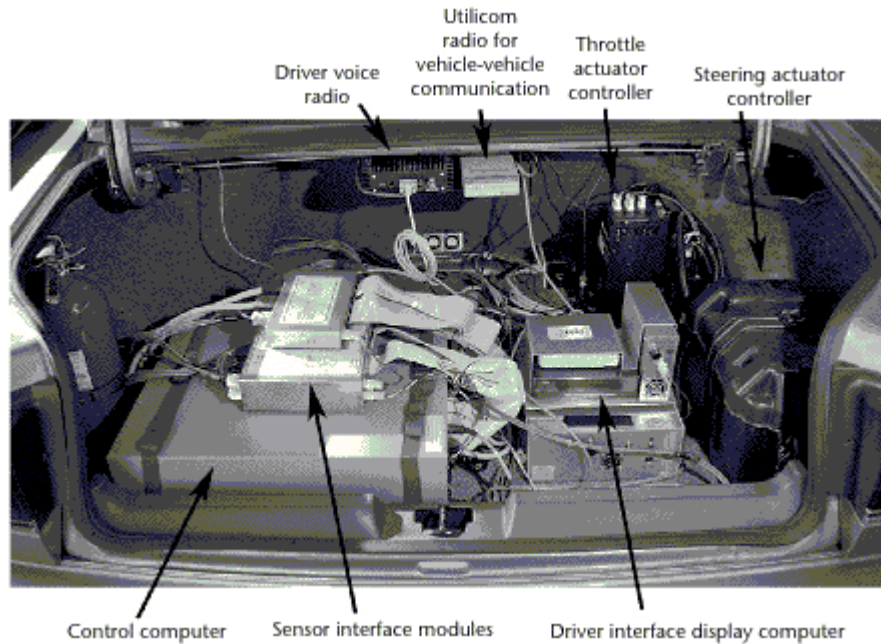
Figure 10- Equipment for Autonomous Operation [8]

There are also projects being worked on for the automation of freight trucks. One example is the European CHAUFFER project. This system acts as an electronic tow-bar where trucks would autonomously follow each other through the use of electronic signaling. The first vehicle in line would be driven by a human and the other trucks in tow would follow at a very close distance through the use of various sensors and systems. This could eventually develop into systems where there is no need for a lead driver and would remove the use of labor in freight transportation.
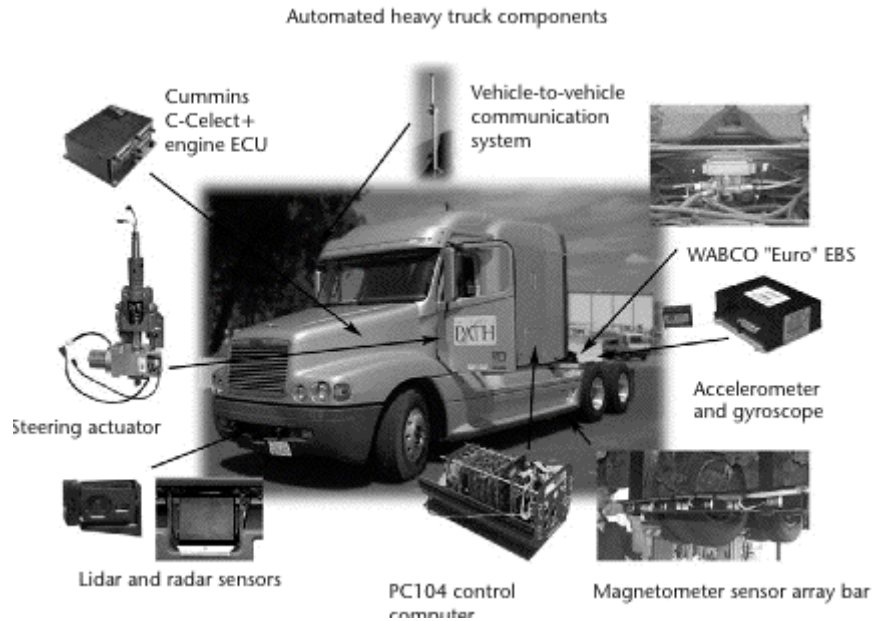
Figure 11 - Sensors Used in Truck Automation [8]

Automated public transportation is currently available through the use of rail systems such as subways, streetcars, or trains.   In the development of autonomously driven vehicles for public transportation, FROG Navigation Systems[15] is the leader in emergent technology.   The company produced the technology for the ParkShuttle system that is used in Amsterdam.   It uses pre defined maps of the area in junction with measuring wheel revolutions and using embedded RF transponders to accurately locate the vehicle position on the map. Ultrasonic sensors are used to detect any objects around the perimeter of the vehicle.

1.3.3 Summary

Technology used in autonomous applications is becoming a priority for many automobile manufacturers. This is shown by the development and implementation of systems such as ACC and LKA. While they are currently only used to assist the driver with tasks, continuing research will eventually lead to the integration of a fully autonomous suite for all types of vehicles. The various systems described above are the building blocks to achieving a fully autonomous system. Integration of these parts combined with writing programs to utilize the hardware is the final step for completion. The difficult part will be creating algorithms that are resistant to failure, and have perfect fail-safe responses. People will only begin to trust a computer to drive their vehicle when it has proven it is near flawless. This will be shown as the product is introduced over time. There will not be an automatic switch from regular cars to autonomous vehicles, but a long transition period where the new cars will catch on slowly. Eventually, there will be few human driven cars on the road, and the majority will be autonomously driven.

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2 Socio-economic Impacts

2.1 Introduction

This section contains an analysis of the possible impacts of the implementation of autonomous vehicles on the society. Modern transportation has a very important role in the world. Transportation is a very fast evolving sector, which is highly associated with new technologies. Autonomous vehicle systems are one of the research areas in the transportation sector that shows great potential for development. There is no doubt that vehicles are getting smarter every day. In our time, the technology is changing so fast that it is hard for people to adapt to it. Making educated guesses about the future developments and determining their possible outcomes helps people understand and prepare for these changes. This is why it is important to determine possible outcomes of the implementation of autonomous vehicle technologies.

This section will elaborate on the socio-economic impacts of autonomous vehicles. The following are the important topics that will be discussed in this section:

- Better fuel economy

- Improved safety

- More efficient traffic flow

- Savings in professional driving

- Time savings

- Changes in culture

- Vehicle maintenance

2.2 Safety

Safety issues have the most serious impact on daily life out of all the transportation problems. Traffic accidents have colossal negative effects on economy. For example, in the European Union, there are over 40,000 fatalities with about 1.3 million accidents every year[4]. The number of fatalities in traffic accidents in the EU between the years of 1970 to 2001 can be seen in *Figure 12.* These 1.3 million accidents cost around 200 billion per year which is equivalent to 2 percent of the EU Gross Domestic Product.[4] Traveling by car is currently the most deadly form of transportation, with over a million deaths annually worldwide. For this reason, the majority of the research projects in the transportation sector concentrate on developing safety systems. These projects mostly fall under the category of intelligent vehicle safety systems.
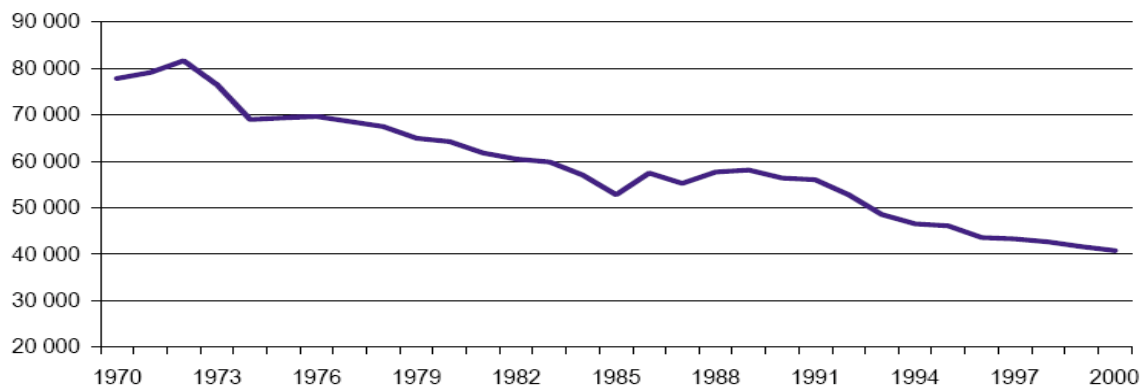
Figure 12 – Fatalities in traffic accidents in the EU[5]

According to research done in Germany, human error is the major cause in more than 90 percent of the accidents, and in almost 75 percent of the cases human error is the only cause. As an example, a recent study concluded that applying brakes half a second earlier in a car traveling at 50 km/h can reduce the

crash energy by 50 percent. But an analysis of German accidents showed that 39 percent of drivers didn't activate their brakes before the collision, and 40 percent didn't apply brakes effectively.[4] This data clearly illustrates that human beings are far from being perfect drivers.

Implementation of autonomous vehicles can greatly reduce the number of crashes, since 90 percent of the traffic accidents are caused by human error. Intelligent safety systems that are currently in use have already proven their success in helping drivers avoid accidents. According to EUROSTAT data, the number of road fatalities in the EU has been reduced from 56,027 to 39,849 people per year between the years of 1991 and 2001.[5] This data indicates a reduction of about 30 percent, which reflects the better safety performance of recent vehicles when compared to previous vehicle generations. The table in **Figure 13** shows the statistical data on the number of persons killed in traffic accidents per million people. The decreasing trend of deaths can clearly be seen in the statistics in **Figure 13**.

	1990	1995	1996	1997	1998	1999	2000
Belgium	198	143	134	134	147	137	143
Denmark	123	111	98	93	94	97	98
Germany	139	116	107	104	95	95	91
Greece	202	231	206	200	207	201	198
Spain	232	147	140	142	151	145	145
France	198	154	147	145	153	145	137
Ireland	136	121	125	128	123	109	109
Italy	126	123	116	117	110	115	111
Luxembourg	186	171	171	143	134	134	174
Netherlands	92	86	76	75	68	69	68
Austria	202	150	127	137	119	133	120
Portugal	305	273	275	253	243	192	181
Finland	130	86	79	85	78	83	77
Sweden	90	65	61	61	60	65	67
United Kingdom	94	64	64	63	60	60	60
EU-15	155	125	118	115	114	111	109
index 1990 = 100	100	80	76	75	74	72	70

Figure 13- Number of persons killed in road accidents per million inhabitants [5]

Every life lost in a traffic accident has a very high financial cost to the community as well as its appalling social effects on people. Their intelligence, work-force and social values are lost with the people killed in traffic accidents. Even injuries have huge financial effects, since treatment costs are very high and the injured people are unable to work for a period of time. The human costs of traffic accidents are shown in more detail in the block diagram shown in *Figure 14*.

```
- in-patient costs
- out-patient costs
- rehabilitation costs
- nursing costs
- post-treatment costs
- aid costs
- support costs
```
                                    Direct
                                 reproduction
                                    costs

                                                        Reproduction
                                                           costs
```
- police costs
- legal costs
- insurance costs
- replacement costs
- death benefit
```
                                    Indirect   Market
                                 reproduction   Price
                                    costs   Approach   Economic
                                                                                costs of traffic
                                                                                  accidents
                                                                 Productive
                                                                   Value
                                                                 Approach
```
- length of time unfit to work
- duration of in-patient
  treatment
- duration of rehabilitation
  treatment
- duration of nursing period
- reduction in earning capacity
```
                                                          Resource
                                                           losses

Figure 14 – human costs of traffic accidents[6]

This diagram shows the ways in which an injury or death can cause economic losses. The top part summarizes the direct costs such as treatment costs; the middle block contains the indirect costs such as police costs and the bottom part mentions the resources lost such as time. All these costs added contribute to the total economic costs of traffic accidents as human costs.

Billions of dollars are lost every year because of the traffic accidents worldwide. The most effective solution to this problem is the implementation of better intelligent vehicle safety systems which will eventually evolve into fully autonomous vehicles. The implementation of autonomous vehicles seems to be a very profitable investment in the long run. **Figure 15** shows the economic impact channels of intelligent safety systems.
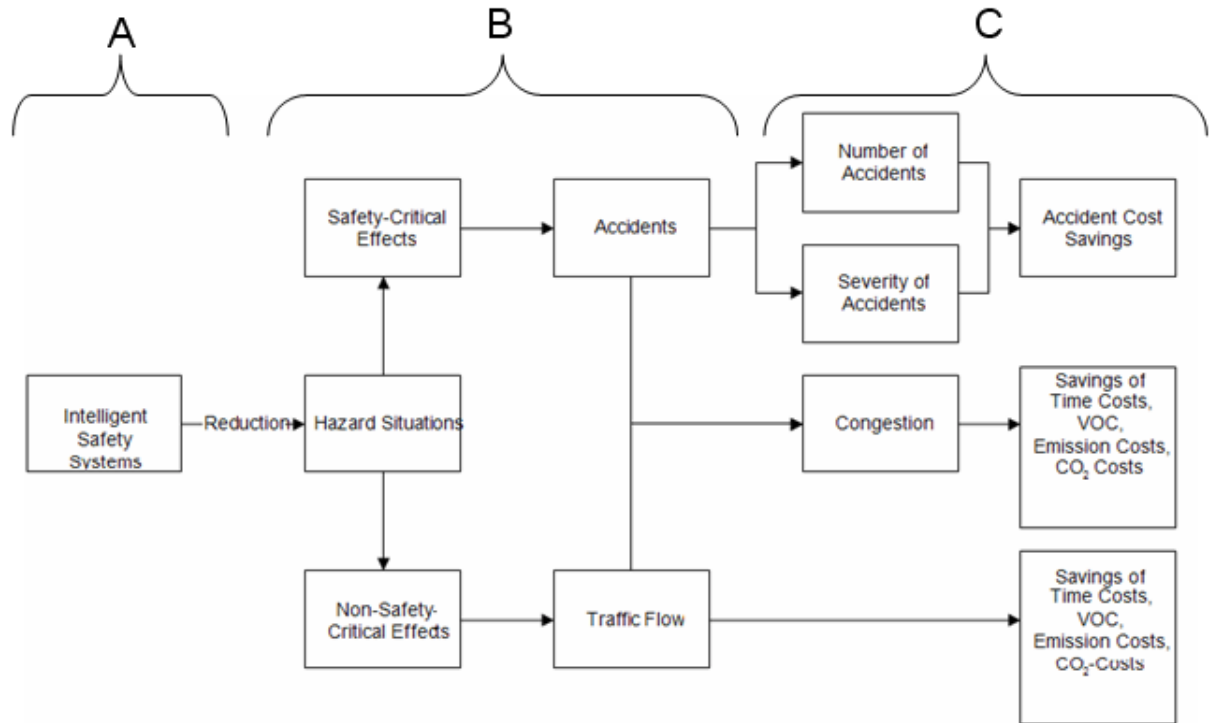
Figure 15 - Impact channels of intelligent safety systems[6]

As it is seen in the block diagram, many benefits can be obtained by avoiding hazard situations. The diagram starts with part A that assumes that the implementation of intelligent safety systems will significantly lower the number of hazard situations faced in the traffic. In part B, the results of reduction of hazard situations is divided into two parts: safety related effects which are mainly accidents and non-safety related effects such as better traffic flow. Part C gives further detail about the ways in which these effects create benefits such as accident cost savings and time savings.

An economical analysis done on a recent European project called "eCall" illustrates how intelligent systems can help the economy. The eCall project aims implementing a special emergency system on every car. This system automatically triggers an emergency call if the vehicle is involved in a serious accident.

According to the analysis done, if an eCall system was installed in every vehicle, deaths in traffic accidents could be reduced by up to 15 percent, reducing the human toll, saving up to 22 billion in social costs per year in the EU. This study also states that eCall could reduce congestion times up to 20 percent, saving an extra 4 billion.[4] A benefit-cost analysis done for this project can be seen in *Figure 16*, which indicates that this system is capable of bringing up to 8.5 times more economic value than the money that will be invested in it. Scenario A is calculated assuming a low impact and scenario B is calculated assuming a high impact.

Annual Benefits	Scenario A	Scenario B
Accident Cost Savings	5,700 Million €	21,900 Million €
Congestion Cost Savings	170 Million €	4,000 Million €
Total Benefits	5,870 Million €	25,900 Million €
Annual Costs	Scenario A	Scenario B
System Costs	4,500 Million €	3,000 Million €
PSAP Equipment Costs	5 Million €	3 Million €
Training Costs	45 Million €	27 Million €
Total Costs	4,550 Million €	3,030 Million €
Benefit-Cost Ratio	1.3	8.5

Figure 16- eCall benefit-cost analysis [6]

2.3 Impacts on Traffic

With the introduction of a fully autonomous vehicle, traffic flow would drastically change. Traffic is currently a nuisance to drivers all over the world. In 2001, the average person in the United States waited for 26 hours in traffic during the whole year. This is a very large amount of total time spent waiting doing nothing by a myriad of people. In the early stages of implementation to the highway system there would be a combination of autonomously driven vehicles and human controlled vehicles. This could cause some confusion and problems concerning the reaction of motorists to the driverless vehicles and how well the autonomous vehicles can integrate into traffic flow. The autonomous vehicles would be following all traffic laws while human drivers have the choice to break the law.

As time progresses and the autonomous car becomes a more commonly used vehicle on the road, traffic would become far less congested. Cars would be able to seamlessly merge into moving traffic and then exit the highway just as easily. With the reduction of traffic, there is a chance that there could be economic improvements. Vehicles could be designed to optimize fuel usage at common speeds used on the road. The speed limit could be increased because there is no longer any concern with human error, and the vehicle would know how to control its situation on the road. Also, with less stop and go traffic, average fuel economy would be improved. Vehicles are also following each other consistently which would help with fuel usage as well.

Also, fewer cars would be traveling on the road because it would be easier to car pool. The vehicle would be able to pick a person up and also drop

them off, allowing the car to drive multiple people to different destinations. Having fewer vehicles and many or all of them on the road at a consistent speed would result in far fewer traffic jams. Because of this, people are happier with their drive and it also reduces the amount of time a person must wait on the road. This is currently a problem that departments of transportation are working on all over the world.

With the time waited on roads being reduced, the ability to improve the overall efficiency of society is realized. This would also force the average person to be on time more than before. They no longer have the choice of leaving for work late and speeding to make it in on time. Any amount of extra time a person has in their job could help with improving the performance of the business. If everyone arrives to work exactly on time the workday begins at that point. An extra five minutes for each employee in a large business would add up to a large amount of extra time put in. With the autonomous car following all of the traffic laws, each person would have to be ready to leave for their destination with enough time for the autonomous vehicle to drive them there.

Parking is also a traffic related problem that affects most cities. This problem is also the major cause of congestion on busy streets. Implementation of an autonomous transportation system will be very helpful in solving this problem, since they would be able to go and park themselves at a more distant location and come back when they are needed. So more convenient parking feature of autonomous cars will help saving time and reduce congestion on streets.
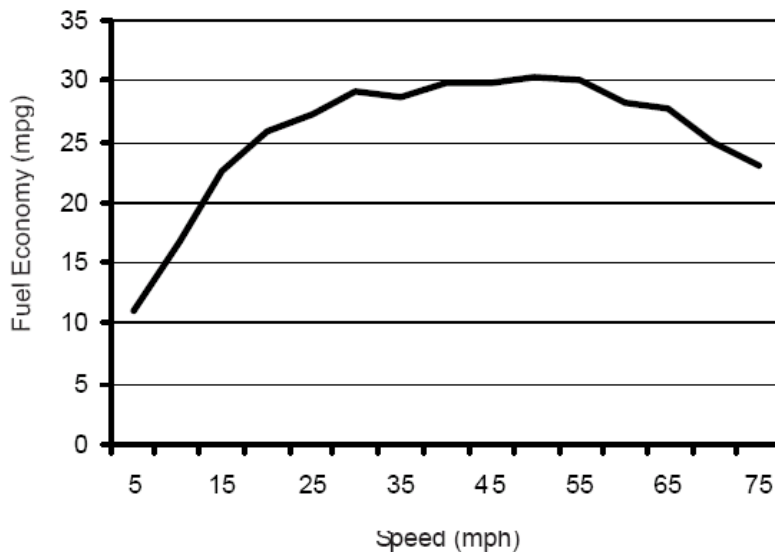
2.4 Fuel economy

Autonomous vehicles will eliminate ineffective speeding up and braking, operating at an optimum performance level in order to achieve best possible fuel efficiency. Even if the fuel efficiency achieved by the autonomous vehicles were 1 percent better, this would result in billions of dollars of savings in the US alone.

In 2004 there were 237,242,616 vehicles registered in the US[2] and an average vehicle in the US traveled 12190 miles using 715 gallons of fuel, which states that the average efficiency was 17.1 miles per gallon of fuel.[1] (These statistics include an average of all motor vehicles including trucks, vans etc.) The total fuel expenditures incurred during 2004 can be calculated by multiplying together the gallons of fuel used per vehicle in the year (715), the price of fuel and the number of vehicles that were registered in the USA in 2004. (For simplicity, fuel price per gallon is taken as $2.50.) According to this calculation, in 2004 people in the USA spent 424 billion dollars for fueling their vehicles. In this case, every one percent increase in fuel efficiency would save about 4.2 billion dollars per year. The fuel expenditures are getting higher and higher every year as the number of vehicles increase and fuel prices are also increasing, which points out the importance of saving fuel.

An aggressive driver uses up to 33 percent more fuel than an average driver and an average driver uses about 10 percent more fuel than most efficient driving possible.[3] Therefore, it would be reasonable to say that autonomous vehicles will be saving more than 10 percent fuel on average. Only this 10 percent by itself can save about 42 billion dollars per year in the USA according to the calculation made in the paragraph above.

As discussed in the earlier safety section, in the future the risk of having an accident will be extremely low if all the cars in use become automated; this will enable all the vehicles to be lighter with the absence of safety features that are not necessary. Making cars lighter will save up to 2 percent fuel for every 100 pounds of weight dropped[3] which would result in about 8.5 billion dollars of savings per year in the USA according to the 2004 figures.

The rates of fuel savings will go even higher when the effect of a better traffic flow is added. Vehicles spend much more fuel than average when they are in stop and go traffic or when they are going too fast. The table below shows the average fuel efficiency of vehicles versus their speed:

Figure 17-Fuel Economy versus speed [3]

It is clearly seen from the figure that the most fuel efficient speeds are between 25 to 65 mph, which match with most speed limitations. In current driving conditions most drivers usually stop very often, drive too slow because of bad traffic conditions or drive too fast on the highway to reach their destination

earlier. With the implementation of a fully autonomous system, vehicles can travel more efficiently in urban areas as well as highways. This will cause the in city mileage ratings of vehicles to get closer to the highway ratings which are about 30 percent higher. Although, improving the level of the efficiency in urban areas to the highway levels will not possible; the efficient flow of traffic in cities can easily save about 10 percent on fuel costs.

It is possible to obtain superior fuel efficiency as a result of the implementation of autonomous safety systems. Total savings that can be achieved by the increased fuel efficiency can be calculated by making some assumptions such as:

- 10% as a result of more efficient driving

- 5% as a result of cars being 300 pounds lighter on average

- 10% as a result of more efficient traffic flow

According to the assumptions made above, the implementation autonomous vehicles will result into fuel savings of 25 percent, which is rough estimate. Using the calculation made in the beginning of this section, the total savings for one year in the US is found to be 104 billion dollars based on the 2004 values.

2.5 Professional Driving

2.5.1 Shipping

Autonomous vehicles will have a huge impact on the land shipping industry. One way to transport goods on land is by freight trucks. There are thousands of freight trucks on the road every day driving for multiple days to reach their destination. All of these trucks are driven by a paid employee of a trucking company. If the trucks were able to drive on their own, a person to move the vehicle from one point to another is no longer needed. The truck is also able to drive to their destination without having to stop to sleep, eat, or anything besides more fuel. All that is necessary is someone to load the vehicle and someone to unload the vehicle. This would save trucking companies a very large amount of money, but it would also put thousands of people out of jobs. These people would have to find and learn a new profession as driving a freight truck is a full time job with little time spent at home to learn how to do another profession. This is potentially life ruining for many employees in this industry.

The U.S. Department of Labor ran an Occupational Employment Statistics survey in 2004 of the Boston metropolitan area[7]. This survey states that there were 12,930 people employed as a heavy truck driver and they made approximately $41,120 per year as a salary. With drivers no longer necessary, all companies employing truck drivers will save a total $531,681,600, or spend it in ways to improve the business.

Not only would freight trucking be affected, delivery services such as FedEX or UPS could the have vehicles driven by autonomous cars. A truck could autonomously drive house to house dropping off packages to people. The

Occupational Employment survey has 10,240 employees listed, making a salary of $31,540 per year. Again, this saves money in the mount of $322,969,600 per year for the industry but takes jobs away from people. There must be a balance if this were to happen. There would need to be some place for employees being replaced to transfer into.

2.5.2 Taxi Services

Another business that would be strongly affected is taxi services. It is based solely on driving someone around who does not have a car or does not want to drive. Then an employee is dispatched to go and pick up the person and bring them to their destination. This type of service could lower the number of vehicles on the road because not everyone would have to own a car, people could call to request an autonomous car to bring them around. Taxis also drive around cities and wait in busy areas for people to request a cab. A taxi service comprised completely of autonomous vehicles could be started. A person can call in and request to be picked up and then be brought to their destination for a fee. There could be autonomous taxis waiting in designated areas for people to come and use them. Many taxi drivers need the job because they are unable to perform other jobs for various reasons. The need for a human in the service goes away almost completely. This is another example of a large amount of people being removed from their jobs because of autonomous vehicles being able to perform the task without the need of an extra person.

According to an Occupational Employment Statistics survey of the Boston metropolitan area[7], the number of taxi drivers and chauffeurs employed was

approximately 2,760 people. Each one of these people is making an average $23,770 per year plus gratuities. They would no longer be making this money if autonomous vehicles became the normal driving vehicle. While this is a huge loss for employees, the companies are no longer paying out a total of $65,605,200 per year for labor. For a taxi service employing only 20 people, that is a savings of $475,400 per year while still making money from offering a taxi service.

An autonomous vehicle can replace two drivers in the eyes of the employer. It does not need to rest and can be on the road as long as it has fuel, and even then it will know when it needs to fuel up so it can return the road as quickly as possible. If a taxi business is not spending $47,540 per year on two employees it could want to invest the money in autonomous systems if it is economically worth it. If an autonomous vehicle system can last for eight years, then the cost for the system must be less than the cost of two taxi drivers over the course of eight years. This means that an autonomous system must cost less than $380,320 for the owner to want to purchase it. It is very likely that the cost of a vehicle equipped with an autonomous system will not exceed this price. The systems use some currently available technology that does not exceed a few thousand dollars, and the remaining technology could not cost over one hundred thousand dollars to equip on a vehicle. This difference in cost will make companies very willing to pay for the new technology.

One unique service that could come from this is the possibility to buy shares in a vehicle. People could own part of a car like they would a timeshare or a shared private jet. Different people buy into a share of the vehicle and then can request specific times to use it, or it can be set up on a schedule of when people can use it. A large corporation could buy into shares of cars all over the world so

wherever an employee went they would have a vehicle available for use. This would also eliminate the need for a chauffeur to drive a company vehicle around.

2.5.3 Public Transportation

Various forms of public transportation are controlled by a human operator. Whether it is on a bus, in a train, subway, streetcar, or shuttle, there is a person sitting in the driver's seat and they are controlling what the vehicle is doing. For trains and other rail-based transportation, it is a simpler process more involved with accelerating and decelerating the train from and into stops with no concern over keeping in a lane. However, on a bus or shuttle, a person must follow rules, watch the actions of other drivers and pedestrians, keep the bus in lane, and make sure they stop at every bus station. These are many tasks that one person must be able to handle and react to and control at the same time. In the early stages of implementation, it would most likely keep the driver behind the wheel as a safeguard incase there is a problem with the system. The driver would also be needed in the beginning in order for the general public to trust it at first. As the life of the autonomous vehicle systems progresses, bus drivers would no longer be needed as the system would be able to perform all of the required tasks. It is a simple job of following a specific route and stopping at designated points. The problems would arise from actions of other vehicles in the area. The most ideal situation is when the autonomous vehicle systems have matured to the point that nearly every vehicle on the road is autonomously driven. This would allow for information exchange between vehicles so they can know the planned moves and

choices that another vehicle in the environment will make. In the end, drivers will no longer be needed to run the bus transit system. This would bring about a large savings for the transit companies that employ all of the bus drivers. The Department of Labor Survey performed in 2004 of the Boston metropolitan area[7] lists 5,500 people as bus drivers, making a yearly salary of $29,000, which is a total savings of $159,500,000 per year. This is a huge savings for the Boston, MA owned bus lines if people are no longer needed to drive the busses.

In total, $1,079,756,400 would be saved in the industry of professional driving. These savings are only from labor, which also means the loss of jobs for 31,430 people only in the Boston, MA area. If these systems become dominant nationwide, or even worldwide, the amount of money saved and also the amount of jobs lost grows extremely fast.

Nearly all forms of professional driving could be taken over by autonomous systems that can perform the task without being paid or given benefits. This brings a huge money savings for companies that run transportation systems, but it will put thousands of people out of work. Unless there is a new type of plant opened to build these autonomous systems, the displaced workers have no where to go right away. They would need to learn a new skill or profession and then try to get a job. This could be easy for newer employees, but for older people it could be much harder. There would need to be much discussion on how to handle this issue before autonomous systems are brought to realization.

2.6 Time Costs

The phrase 'time is money' is true for most situations in modern life and the monetary value of time is increasing every day. Using automated cars could save considerable amount of time in a person's life, especially if the person resides in a busy city. Even if the time savings were not considered as having monetary value, having more time for leisure activities would raise our life standards. Lowering the amount of time lost will also enable people to be on time and more dynamic, resulting in a significant improvement in work efficiency.

One of the biggest advantages of this technology will be the elimination of traffic problems in cities, which are at the top of the most frustrating problems list for most people. By enabling a smoother traffic flow, the new system will be saving a lot of time which can be used for work or leisure. The table below shows the time cost unit rates of operating a vehicle per hour:

Vehicle Category	Cost-Unit Rates		
	Germany (Base Year 2000)	United Kingdom (Base Year 2000)	USA (Base Year 1997)
Average Passenger Car	11 €/h	13 €/h	8.9 $/h
Average Truck	32 €/h	14 €/h	16.5 $/h
Average Bus	66 €/h	82 €/h	--

Figure 18-Time costs of operating a vehicle [6]

In this table the cost unit rate used for commercial vehicles was taken to be 32   per hour and for leisure purposes it was taken to be 9   per hour. Busses seem to have a higher cost of operation since they are assumed to be used commercially.

Another important time saving aspect of the autonomous vehicles is that they will enable their users to do work or rest while they are traveling. This way every road trip will be like a plane trip in the business class without the annoying engine sound of the plane. With the implementation of autonomous cars people will no longer need to leave their work in order to pick up their children from school. The self parking feature could also save significant amount of time as well as the auto-maintenance feature which is discussed later in the document.

2.7 Cultural Changes

There are many cultural traditions that revolve around being able to drive a vehicle. In the United States, a major milestone in a young person's life is getting a drivers' license. It is anticipated by every teenager approaching the age to take drivers' education, take a driving exam, and then have a license to drive anywhere. Many teenagers also get their first vehicle at this time as well. It is like a coming of age rite because of the need to be able to go where a person wants at any time. Also, useful knowledge of the roads comes with getting a drivers' license. What we consider common sense because everyone has to learn the rules of the road would no longer be known by all people on the road. The vehicle knows how to drive and follows all of the rules so it is not essential to learn all of the information. When the vehicle becomes fully implemented, it would seem as though this knowledge would no longer be known by the average person, and therefore no longer thought of as common sense. If autonomous vehicles became widespread, it is no longer as necessary to get a drivers' license. A vehicle can pick a person up from any location, and then also bring them to any destination. It will no longer be desirable to own a personal vehicle when one can be easily shared among multiple people. A family owned autonomous vehicle would be able to service the entire family. There is no longer a need to have the parents drive the children to drop them off at a destination because the child is too young to drive on their own. This responsibility is then no longer passed down to the oldest child in a family when they get their license. This would be a revolutionizing impact on family life. However, these types of changes would only occur when the autonomous vehicle is widespread. In the early stages it will

not have much influence on how people go about their every day life. It will most likely have some resistance because people will not want to give up the control of driving and needing to get a license to be able to move them as they please. As the benefits become more apparent, people will realize how effective and helpful it can be.

There is also a complete culture behind the modification of vehicles for racing, aesthetics, or to suit personal interests. There will always be auto-enthusiasts that will keep their car because of the amount of time and heart put into the changes. The feeling of taking a nice car out for a drive on a nice sunny day on fun roads can never be replaced. A modified car shows a part of a person's character. If a car is shared among multiple people, it is harder for someone to want to put work into modifying a vehicle. There is no doubt that the implementation of autonomous vehicles will hurt the culture and economy surrounded around personal car modification.

2.8 Better Maintenance

With the ability to drive anywhere on its own, an automated vehicle could take itself to gas stations or regular service and repair, provided that those services are arranged for autonomous vehicles. These self maintenance abilities can save time and make sure that the car is in good shape at all times. The automated vehicles will also minimize the abuse of the vehicle in a way so that the minimum service or spare parts will be required. As a result, cars will experience fewer breakdowns and have a longer engine life while being more cost-effective and reliable. A very important effect of the self maintenance ability would be minimizing the number of crashes that are caused by technical faults.

The fuel economy that can be obtained by taking good care of a vehicle shouldn't be ignored:

• Replacing a clogged air filter can improve a vehicle's gas mileage by as much as 10 percent.

• Fixing a car that is out of tune can improve its gas mileage by an average of 4 percent.

• Keeping the tires inflated to the right pressure can save about 3.3 percent.(3)

It is possible to calculate savings estimates based on the earlier calculations made in the fuel economy section. Assuming that about 5 percent of the vehicle owners do not perform the maintenance activities that are listed above, the resulting total savings that can be obtained by performing proper maintenance is 3.67 billion dollars per year in the USA. Replacing air filters contributes to this total by 2.12 billion dollars, followed by 0.85 billion dollars for tuning and 0.7 billion

dollars for having the right tire pressure. (These calculations are based on the data from the year 2004)

Conclusion

Currently, there are many different technologies available that can assist in creating autonomous vehicle systems. Items such as GPS, automated cruise control, and lane keeping assistance are available to consumers on some luxury vehicles. The combination of these technologies and other systems such as video based lane analysis, steering and brake actuation systems, and the programs necessary to control all of the components will become a fully autonomous system. The problem is winning the trust of the people to allow a computer to drive a vehicle for them. Because of this, there must be research and testing done over and over again to assure a near fool proof final product. The product will not be accepted instantly, but over time as the systems become more widely used people will realize the benefits of it

The implementation of autonomous vehicles will bring up the problem of replacing humans with computers that can do the work for them. There will not be an instant change in society, but it will become more apparent over time as they are integrated into society. As more and more vehicles on the road become autonomous, the effects on every day life will be shown. It will result in an increase of the efficiency of many companies as less time is wasted in travel and less money is spent on tasks autonomous vehicles can perform where a human was previously needed. This will also cause the loss of thousands of jobs all over the world. There would have to be a plan in place before society would allow this to happen. This is an important reason behind the lack of interest and slow development of fully autonomous vehicles. If this problem is solved, we could see fully autonomous vehicle systems in the near future.

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